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# Impact of non-axisymmetric magnetic field perturbations on flows

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# Introduction

Plasma rotation plays a key role in plasma confinement [1][2];

Control of plasma rotation in reactor-sized tokamak is challenging [3];

Intrinsic bulk plasma rotation is driven by turbulence and *Neoclassical Toroidal Viscosity* **(NTV)**;

# **Theoretical model**

- A reduced model based on the mean toroidal velocity  $V_T$  reads :

 $\frac{\partial V_T}{\partial t} = \text{Neoclassical Toroidal Viscosity} + \text{Turbulent torque}$ 

**Ripple** constrains  $V_T$  through neoclassical friction  $\nu_{\omega}$ 



**Turbulence** constrains  $V_T$  through turbulent viscosity  $\chi_{turb}$ 



Magnetic field ripple is responsible for the NTV.

**Objective: Understand the** competition/synergy between turbulence and **NTV** with gyrokinetic simulations.



FIG.1 – Kinetic effects induced by ripple : drift of banana bounce points (a) and toroidal trapping between coils (b). Neoclassical friction  $v_{\varphi}$  comes from the collisions between trapped populations.



FIG.2 – Snapshot of the turbulent structures seen through a colormap on the electric potential. From rest,  $V_T$  grows due to wave-particle interactions.

<u>Goal</u>: Obtain coefficients of turbulent momentum transport from simulations and use neoclassical friction  $\nu_{\varphi}$ predictions to find the ripple amplitude threshold for which neoclassical effects overcome turbulence.

### **Neoclassical friction** Turbulent momentum transport - Turbulence impacts $V_T$ through the toroidal Reynold's stress $\Pi_{\omega}$ Ripple is responsible for magnetic braking *M* in the toroidal direction : the NTV; Axisymmetric theory [4][5]: $\Pi_{\varphi} = -\chi_{turb} \frac{\partial V_T}{\partial r} + \mathcal{V}V_T + \Pi_{res}$ (Eq.1) Neoclassical theory [6][7] with ripple gives : $m = -\mathbf{v}_{\varphi} \left( V_T - k_T \frac{\nabla T}{eB_P} \right)$ Viscosity Pinch Residual - Obtention of $\chi_{turb}$ , $\mathcal{V}$ and $\Pi_{res}$ using gyrokinetic simulations : Simulations of turbulent plasma without ripple with different initial toroidal velocity **Thermal drive** Friction $\rightarrow$ FIG.3 shows the dominance of the viscosity : $-\chi_{turb} \frac{\partial V_T}{\partial r}$ ; GYSELA code shows good agreement with

- Eq.1 defines a plane in the  $(V_T, \partial_r V_T, \Pi_{\varphi})$  space;
- Mean square plane fit using simulations output gives an estimation of  $\chi_{turb}$  within a radial range (see FIG.4 for an example). 0.5 < *ρ* < 0.57  $V_0 = 0.0$





FIG.3 - Radial profiles of  $V_T$ ,  $\partial_r V_T$  and  $\Pi_{\varphi}$  taken at turbulent saturation for simulations initialized at different toroidal velocity  $V_T(t=0) = V_0 e^{4(\rho-0.5)^2}$ 

FIG.4 - Plane fit of  $\Pi_{\varphi}$  using point cloud from simulations giving an estimation of the turbulent viscosity within a radial range.



neoclassical predictions;

 $- v_{\omega}$  increases with the ripple amplitude.

## Conclusion

Ripple is responsible for a neoclassical friction that constrains the toroidal velocity;

**Turbulence** is a source of intrinsic rotation;

Evolution of mean toroidal flow ruled by competing turbulent stress and ripple drag forces;

The radial electric field grows in response to the modification of the toroidal velocity;

Simulations suggest that neoclassic drag overcomes turbulent stress for typical realistic ripple amplitudes in WEST;

with realistic WEST ripple amplitude is necessary to understand the shape of  $\frac{dE_{\gamma}}{dr}$  and the transition toward high-confinement modes. References [1] T. S. Hahmand and K. H. Burrell, PoP 1995 [2] P. Mantica, PRL 2009

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